

The Use of Remote Sensing and GIS to Estimate Air Quality Index (AQI) Over Peninsular Malaysia

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Abstract:

The recent August 2005 haze episode was not a new experience for Malaysia as this phenomenon has been occurring almost every year. History revealed that the worst haze episode took place during May-November 1997. On the 23rd September 1997, the Sarawak capital, Kuching was declared in the state of emergency as its Air pollution Index (API) reached 839. This was the highest API ever been recorded in Malaysia. This paper reports result of a study in order to compute API using satellite-based method. Seven dates of NOAA-14 AVHRR satellite recorded data were used, representing seven days during the September 1997 thick haze episode in Malaysia. Five locations of air pollution station were selected where major pollutants have been measured conventionally. Haze information was extracted from the satellite data using sky-light model. Relationship between the satellite recorded reflectance and the corresponding pollutant measurement was determined using regression analysis. Finally, accuracy of the result was assessed using RMSE technique. The result proven that satellite-based method using space-borne remote sensing data was capable of computing API spatially and continuously.

1 Introduction

Haze is said to be a partially opaque condition of the atmosphere caused by very tiny suspended solid or liquid particles in the air (Morris, 1975). Haze (originating from open burning or forest fire) usually contains large amount of particulate matter (e.g., organic matter, graphitic carbon). This particulate matter is hazardous to health, especially associated with lung and eye deceases. Besides that it is capable of reducing visibility, increasing the atmospheric greenhouse effects and affecting the

tropospheric chemistry.

Conventionally, PM 10 can be measured from ground instruments such as air sampler, sun photometer and optical particle counter, however these instruments are impractical if measurement are to be made over relatively large areas or for continuous monitoring.

The haze episode which occurred during mid-May to November 1997 is considered the worst since 1980 (five similar haze episodes had occurred in April 1983, August 1990, June 1991, October 1991 and August 1994). On 19th September 1997 Malaysian government had declared that Kuching (capital of Sarawak) was in the state of emergency when the PM10 API (Air Pollution Index) exceeded 650 (hazardous level). By 23rd September 1997 the condition worsened as Kuching's PM10 API reached 839, the highest ever been recorded by the country.

This paper reports results of a study to determine PM 10 from NOAA-14 AVHRR satellite data. Their concentration and spatial distribution will be quantified based on updated measurement system, AQI. This current study is an extension of previous work by Ahmad and Hashim (1997, 2000, 2002), and Mazlan et. al (2004) that produced models to quantify haze in API.

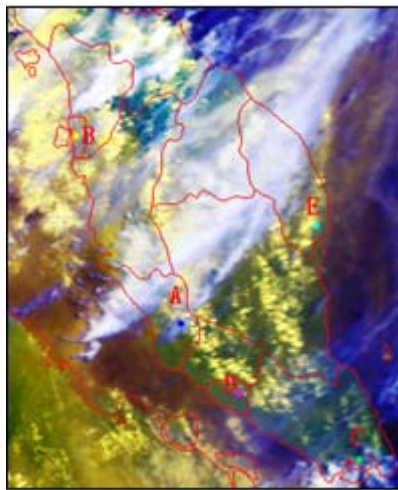


Figure. 1. Raw NOAA AVHRR data dated 22 September 1997. Location of the selected air pollution stations are demarcated as letter A,B,C,D and E designated for Kuala Lumpur, Prai, Pasir Gudang, Bukit Rambai, and Bukit Kuang respectively. Combination of band 1, 2 and 4 are used to visually differentiate between haze (orange), low clouds (yellow) and high clouds (white).

2 Materials

This study involved the usage of three types of data namely; ground-truth data, satellite data and ancillary data.

2.1 Ground-truth data

Conventional measurements of haze were complementarily used throughout performing data processing for extraction of PM 10 information. PM 10 measurements in micrograms per meter cube ($\mu\text{g}/\text{m}^3$) from 1st to 30th September 1997 were carried out by ASMA (Alam Sekitar Malaysia Sdn. Bhd.) to represent the actual haze intensity over the study area. For the purpose of this study, the measurement was later converted to AQI.

Index Values*	Level of Health Concern	Cautionary Statements
0 - 50	Good	None
51 - 100	Moderate	None
101 - 150	Unhealthy for Sensitive Groups	People with Respiratory disease, such as asthma, should limit outdoor exertion.
151 - 200	Unhealthy	People with respiratory disease, such as asthma, should avoid outdoor exertion; everyone else, especially the elderly and children, should limit prolonged outdoor exertion.
201 - 300	Very Unhealthy	People with respiratory disease, such as asthma, should avoid any outdoor activity; everyone else, especially the elderly and children, should limit outdoor exertion.
301 - 500	Hazardous	Everyone should avoid any outdoor exertion; people with respiratory disease, such as asthma, should remain indoors.

*An AQI of 100 for PM₁₀ corresponds to a PM₁₀ level of 150 micrograms per cubic meter (averaged over 24 hours).

Table 1. Air Quality Index (AQI) for Particulate Matter up to 10 micrometers in diameter (PM₁₀)

2.2 Satellite data

Seven sets of NOAA-14 AVHRR data dated 22, 23, 25, 28, 29 and 30 September 1997 acquired from SEAFDEC (Southeast Asia Fishery Development Centre) receiving station were used. NOAA-14 AVHRR was suitable for haze study as it offers high spectral and temporal resolution with a minimum cost. Some useful characteristics of NOAA-14 AVHRR satellite are shown in Table 2.


AVHRR Sensor characteristics		
	Swath width	2399km
	Resolution at nadir	1.1km approx.
	Altitude	833km
	Quantisation	10 bit
	Orbit type	Sun synchronous
	No. of orbits per day	14.1 (approx.)
AVHRR Spectral characteristics		
Channel No	Wavelength	Typical use
1	0.58 - 0.68	Daytime cloud, haze and surface mapping
2	0.725 - 1.00	Land-water boundaries
3	3.55 - 3.93	Night cloud mapping, sea surface temperature
3A	N/A	Snow and ice detection
3B	N/A	Night cloud mapping, sea surface temperature
4	10.30 - 11.30	Night cloud mapping, sea surface temperature
5	11.50 - 12.50	Sea surface temperature

Table 2. NOAA-14 AVHRR sensor and spectral characteristics
(Source: Kidwell et al., 1995)

2.3 Ancillary data

Meteorological information over study area, including visibility (Figure 2), air temperature, pressure, relative humidity, wind, etc were obtained from MMS (Malaysian Meteorological Service).



Figure 2. Reducing visibility of Petronas Twin Towers resulted from the appearance of haze

3 Method

Three modules incorporated in this study are (1) Derivation of haze model, (2) Regression analysis, and (3) Accuracy Assessment.

3.1 Derivation of haze model

Prior to further data processing, post launch calibration of visible Band 1 NOAA-14 AVHRR was earlier implemented in order to compensate data degradation due to extreme temperature change before and after launching of AVHRR sensor to space (Rao et al., 1996). Clouds and haze were successfully differentiated using thresholding technique (Baum et al., 1997). This to ensure both were not being misinterpreted between each other. Model used in this study is based on Siegenthaler and Baumgartner (1996), which make use of skylight to indicate the existence of haze. Skylight is an indirect radiation, which occurs when radiation from the sun being scattered by elements within the haze layer. It is not a direct radiation, which is dominated by pixels on the earth surface. Figure 3 shows electromagnetic radiation path propagating from the sun towards the NOAA-14 AVHRR satellite penetrating through a haze layer. Path number 1, 3 and 4 are skylight caused by direct radiation, whereas path 2 is indirect radiation.

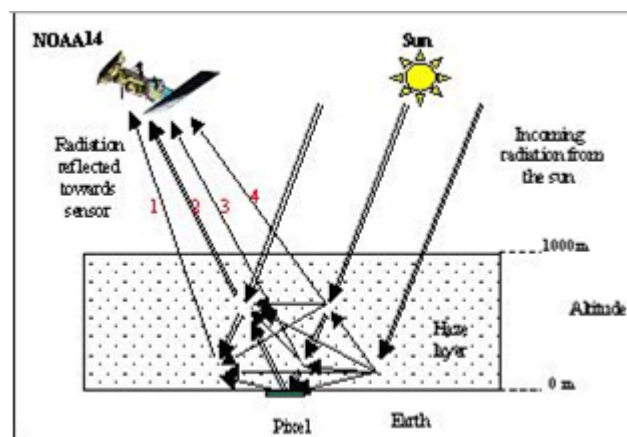


Figure 3. Model used in this study is based on the skylight parameter
(Source : Modified after Siegenthaler and Baumgartner, 1996)

This model can be described by:

$$\sigma - R = L \cdot V \quad (1)$$

where,

σ : reflectance recorded by satellite sensor,

R : reflectance from known object from earth surface ,
L : skylight, and
V : lost radiation caused by scattering and absorption.

3.2 Regression analysis

Calibration pixels of NOAA-14 AVHRR data were sampled within a radius of 2.5 km from each of the air pollution stations. The relationship between PM 10 AQI and satellite-recorded reflectance of band 1 AVHRR, were analysed using linear regression.

3.3 Accuracy Assessment

In order to verify the accuracy of the regression model, RMSE (Root-mean-squared Error) was implemented to the AQI values obtained by the model.

$$RMSE = \sqrt{\frac{1}{n} \sum (AQI_{\text{calculated}} - AQI_{\text{measured}})^2} \quad (2)$$

4 Results

The scatter plot for PM 10 versus satellite reflectance of band 1 NOAA AVHRR with its linear regression trend is shown in Figure 4 where the coefficient of determination, R² is 0.5563. The linear regression model can be expressed as:

$$PM10_Concentration\ (AQI) = (5.174 \times \text{Satellite_Reflectance}) + 77.877 \quad (3)$$

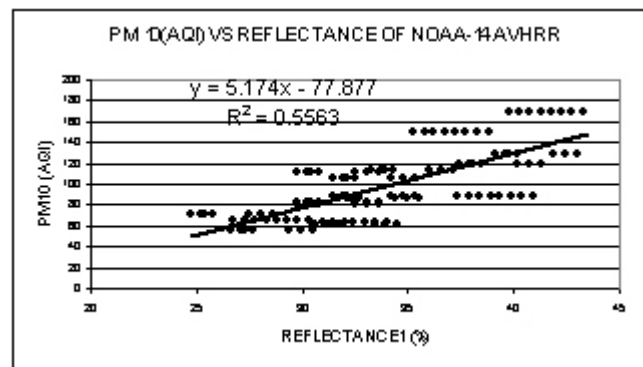


Figure 4. PM 10 in AQI versus satellite reflectance in percentage. Linear regression trend is shown in black line

The RMSE varies accordingly for all the five PM 10 ground stations ranging from 7 to 62 and with the average of 33 (Table 3). It is believed that the relatively high RMSE was due to limited number of air pollution stations used. Future study will consider of using more air pollution stations as well as other value-added ancillary data in order gain better and reliable accuracy.

Location	A	B	C	D	E
RMSE (AQI)	33	35	26	62	7

Table 3. Average RMSE for respective haze components at Penang and Johor Bahru

The spatial distribution of PM 10 can be shown in a colourful map (Figure 5) consisting of regions in green (good), yellow (moderate), orange (unhealthy for sensitive groups), red (unhealthy), purple (very unhealthy) and maroon (hazardous). Cautionary Statements for every region are given in detail in Table 1.